



HONG KONG MONETARY AUTHORITY

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# HKMA Research Letter

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## STRESS TESTING THE BANKING SYSTEM

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### Introduction<sup>1</sup>

The global credit crisis that began in the second half of 2007 is an extreme event in the history of financial industry, both in terms of the scale of losses and the number of affected institutions. According to Bernanke (2008) and Senior Supervisors Group (2008), financial institutions performing better in the crisis are usually those with more effective stress-testing tools in place.

Stress testing refers to a range of techniques used to assess the vulnerability of a financial institution to "exceptional but plausible" macroeconomic shocks.<sup>2</sup> In parallel

with its application for the assessment of the vulnerability of the portfolios of individual institutions at the micro level, stress testing has also been playing an increasingly important role in the macro-prudential surveillance of public authorities<sup>3</sup>, the main objective of which is to identify structural vulnerability and overall risk exposures in a financial system that could lead to systemic problems.

In view of its importance, developing stress-testing methods has long been one of the core areas of interest for the Research Department of the HKMA. To enhance our capability of

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<sup>2</sup> This follows the IMF definition. See Blaschke et al. (2001).

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<sup>3</sup> The importance of stress testing on financial stability is clearly demonstrated by the Supervisory Capital Assessment Program announced in February 2009 by the US federal bank regulatory agencies. In the program, stress testing played a main role in assessing the capital adequacy of 19 largest bank holding companies in the US.

macro-surveillance of the Hong Kong banking sector, the Market Research Division has recently refined its credit-risk stress-testing framework and developed a new framework to stress test banks' liquidity risk. This Research Letter summarises the main results of these two major research projects<sup>4</sup> and also provides some thought on further research.

## **The credit-risk stress-testing framework**

This framework is developed for stress testing the credit exposures of banks in Hong Kong. Broadly speaking, the framework consists of two elements -- first, scenarios of extreme but plausible adverse macroeconomic conditions need to be devised. Secondly, the adverse macroeconomic scenarios need to be mapped onto the impact on banks' balance sheets. Through this, the robustness of banks can be evaluated. The construction of the framework involves building a number of models designed to capture the relationship between the default rate of bank loans and different macroeconomic values based on historical data. For example,

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<sup>4</sup> For details, see Wong et al. (2006), Fong and Wong (2008) and Wong and Hui (2008).

one model is specified for the overall loan portfolios of banks and, to illustrate how the same framework can also be used to stress test loans to different economic sectors, another model is specified for only the banks' mortgage portfolios. The estimation results confirm a significant relationship between the default rates of bank loans and key macroeconomic factors, including Hong Kong's GDP, interest rates and property prices, and the Mainland's GDP.<sup>5</sup>

To conduct the stress testing, adverse macroeconomic scenarios represented by certain shocks are specified and possible combinations of stressed macroeconomic values, which are internally consistent and realistic, are obtained by a Monte Carlo simulation<sup>6</sup> to generate distributions of possible default rates of bank loans under such shocks. Value-at-risk (VaR) is then computed to evaluate how the stressed macroeconomic environment may impact on the default probability of banks' loan portfolios.

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<sup>5</sup> The unemployment rate in Hong Kong is not included as an explanatory variable in the model due to the existence of a high level of multicollinearity between this variable and Hong Kong's GDP growth.

<sup>6</sup> A Monte Carlo simulation is a class of computational algorithms that rely on repeated random sampling to approximate the probability of certain outcomes.

The framework was completed in 2006<sup>7</sup> and has since been put to use for stress testing the credit risks of banks in Hong Kong on a regular basis. In the latest stress-testing exercise, based on the economic and banking conditions in the third quarter of 2008<sup>8</sup>, the credit exposures of the banking system were stress-tested by imposing various shocks similar to that of the Asian financial crisis. Specifically, four different shocks arising from four different stress origins were considered:

(1) HK GDP Shock: reductions in Hong Kong's real GDP by 2.3%, 2.8%, 1.6% and 1.5% in each of the four consecutive quarters starting from 2008 Q4;

(2) China GDP Shock: a fall in Mainland China's real GDP by 3% in only the first quarter (i.e. 2008 Q4);

(3) Interest-rate Shock: a rise of real interest rates by 300 basis points in the first quarter, followed by no change in the second and third quarters and another rise of 300 basis points in the

fourth quarter; and

(4) Property-price Shock: reductions in real property prices by 4.4%, 14.5%, 10.8% and 16.9% in each of the four consecutive quarters starting from 2008 Q4.

In the framework, paths of future default rates under the various shocks, based on the estimated models, were simulated and the accompanying distributions of credit losses were constructed. The assessment of the banking system's vulnerability to adverse economic development was then conducted by comparing the estimated frequency distribution of credit losses of the stressed scenario with that of the baseline scenario, where no artificial adverse shock takes place. Estimated frequency distributions of the default rates for each sector corresponding to the stressed and baseline scenarios were obtained separately by simulating a large number (100,000) of future joint sector-specific default rates through the Monte Carlo method.

In the baseline scenario, the credit loss that could be expected to prevail in 2010 Q3 (or the mean of the credit-loss distribution) was 0.3%. Introducing the assumed shocks substantially

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<sup>7</sup> See Wong et al. (2006).

<sup>8</sup> It was conducted after the collapse of Lehman Brothers, when the global financial markets were under a very stressful environment, despite the unprecedented actions and measures taken by various central banks and governments to inject liquidity in the global banking system.

increased the expected percentage of credit loss. It became 1.2% in the scenario where Hong Kong's real GDP growth rate was shocked from 2008 Q4 to 2009 Q3.

However, the main focus of a stress test is not on the average response to the assumed shocks but on in the tails of the credit loss distributions. The results show that at the confidence level of 90%, banks would continue to make a profit in some of the stressed scenarios, suggesting that the then prevailing credit risk of the banking sector was moderate.

Nevertheless, at the extreme of the credit-loss distribution, implying a confidence level of 99%, banks' credit losses would range from 1.8% of the portfolio under a China GDP shock to a loss of 3.4% under a Hong Kong GDP shock. If a confidence level of 99.9% is chosen, the loss would range from 2.9% under a China GDP shock to 4.9% under a Hong Kong GDP shock. The estimated maximum losses were very similar to what was experienced one year after the Asian financial crisis.<sup>9</sup> However, the

occurrence of such extreme scenarios would have a very small probability of only 0.1%.

## **The liquidity risk stress-testing framework**

As shown by recent development in the US and European banking systems, significant mark-to-market (MTM) losses on banks' financial investments can expose banks to default risk, which could lead to a systemic liquidity crisis. For banking stability, it is important to assess the ability of individual banks and the banking system as a whole to withstand such shocks if they were to occur in the domestic market.

A new stress-testing framework has been built to facilitate the analysis of interactions between default risk and liquidity risk and to assess the vulnerability of the banking system to a prolonged period of negative asset-price shocks. In the framework we assume that there is a one-year period of continued declines in asset prices in some major financial markets, where banks generally have significant exposures. The assets include debt,

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<sup>9</sup> In the event, the credit loss of banks is estimated to have risen from 1.4% before the Asian financial crisis to 6.0% one year after the shock. These rough estimates are based on an assumed loss-given-default of 70%, and the actual default rates of overall loans at 2.01% in 1997 Q3 and 8.58% in 1998 Q4.

equities and structured financial assets. The simulated paths of the asset-price shocks are such that potential losses of banks' on their investment in high-yield corporate bonds, equities and structured financial assets could be more than half of the investment amounts in a one-year horizon.

Given this, the implications for default risk of banks could be substantial since the capital available for banks to serve as a buffer against such MTM losses is limited, as banks usually operate with a relatively high level of financial leverage.

Asset-price shocks may increase banks' liquidity risk both directly and indirectly via the effects on banks' default risk through three channels: First, severe MTM losses on the banks' assets increase banks' default risk and thus induce significant deposit outflows. Secondly, the ability to generate liquidity from asset sales evaporates due to the shocks. Thirdly, banks are exposed to contingent liquidity risk, as the likelihood of drawdowns on their irrevocable commitments increases in such stressful financial environments.

In the framework, the linkage between market and default risks of banks is

implemented using a Merton-type model, while the linkage between default risk and deposit outflows is estimated econometrically. Contagion risk is also incorporated through banks' linkage in the interbank and capital markets. Using the Monte Carlo method, the framework quantifies liquidity risk of individual banks by estimating the probability of cash shortage and the probability of default due to liquidity problems. The corresponding probability of multiple defaults of banks in a banking system can also be estimated, which is important for assessing the systemic risk in the banking system.

The framework has been applied to a group of 12 listed banks in Hong Kong.<sup>10</sup> The stressed scenario considered in this study assumes that (1) prices of non-financial corporate bonds with AAA, AA, A, BBB, and speculative credit ratings decrease on average by 4%, 4%, 8%, 13% and 34% respectively<sup>11</sup>; (2) prices of Hong Kong and non-Hong Kong equities decline by around 20% and 25% respectively; and (3) prices of structured financial assets decrease by more than 50%. It assumes a neutral stance of the US monetary policy and

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<sup>10</sup> See Wong and Hui (2009).

<sup>11</sup> Assuming that the duration of the bonds is 10 years.

thus the risk-free interest rate hovers around the initial level in the stress horizon. As an indirect effect of the fall in asset prices, banks' classified loan ratio increases by 200 basis points and the returns on bank assets fall by 25%. In addition, the portion of sub-prime mortgage-related irrevocable commitments is assumed to be 5%.

The scenario can be thought of as a deepening of the sub-prime crisis in 2008 and its transmission to other asset markets. Specifically, as concerns on default risk heighten, fire sales for high-yield corporate bonds and structured financial assets continue in a similar manner as that occurred during the onset of the sub-prime crisis. This leads to significant decreases in prices in these two markets. In addition, the crisis spreads to equity markets due to unfavourable investment sentiment and the level of severity of stress in equity markets is assumed to be similar to that occurred after the burst of the internet bubble.

With such shocks, even banks without investment in high-risk corporate bonds and structured financial assets also face significant write downs for their investment portfolios. At the same time, the general asset price disruptions

adversely affect banks' operating income and the asset quality of their loan portfolios. The former could be due to significant declines in fee and commission income earned during the very unfavourable asset-market development, while the latter could result from a significant deterioration in the repayment ability of corporate borrowers. Moreover, due to falls in the values of structured financial assets, drawdowns of banks' irrevocable commitments by special investment vehicles that invest in structured financial assets increase significantly, leading to massive liquidity outflows of banks.

In the exercise, we take the balance-sheet conditions of the banks at the end of December 2007 as the initial state. We then simulate daily future paths of the asset price shocks covering the period of January - December 2008. The cash flows of each bank are calculated based on the simulated paths of the asset-price shocks according to the framework. We repeat the process 1,000 times, from which the numbers of occurrences of cash shortage and default are calculated. We also calculate the expected first cash-shortage time and default time conditional on occurrences of cash shortage and default respectively

for each bank. The extent to which individual banks could withstand the shocks is assessed by these liquidity risk indicators.

Based on the estimated probability of cash shortage and the probability of default, the stress-testing results suggest that liquidity risk of banks in Hong Kong would be contained in the face of a prolonged period of asset price shocks, with all the 12 banks estimated to have zero probability of cash shortage or default, even under the then prevailing harsh economic conditions. The findings indicate that the conditions in Hong Kong's banking system are such that the likelihood of a self-perpetuating deterioration in liquidity and default risk is minimal.

## Remarks

Stress testing is an important tool of surveillance for central banks. Given that financial innovations and development are usually accompanied by new risks and challenges for the economy in general and the banking sector in particular, it is important for regulators to stay at the forefront of research on stress testing in order to be

in a position to identify and evaluate possible sources of fragility and signs of instability.

As part of our effort to enhance this tool of surveillance, the following further studies are currently in our research agenda:

(1) The application of using a class of mixture vector autoregressive models for stress testing, which extends the classical vector autoregressive model by assuming the probability distribution of default rate and macroeconomic variables to be a mixture of normal distributions in order to estimate macroeconomic credit risk.<sup>12</sup>

(2) A possible refinement of the existing credit-risk stress-testing framework by allowing the mixing proportion of autoregressive models to change with the variables of interest over time, which allows the dependent variable to change gradually between “normal” and “abnormal” market conditions.

(3) For liquidity-risk stress testing, an examination on how the impact of exogenous asset price shocks would be transmitted to the macro-economy

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<sup>12</sup> See Fong and Wong (2008).

through the dynamics of risk in the banking sector, and how such transmitted macroeconomic effects would feedback to the banking sector to affect banks' operating income and the quality of their loan portfolios.

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